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PUBLICATION OF SEISMOLOGICAL DATA IN THE REVIEW TO BE DISCONTINUED

Announcement is made that a bill (H. R. 8303), quoted hereunder, authorizing the Coast and Geodetic Survey to make seismological investigations and for other purposes, was introduced in the last Congress, passed by the House of Representatives on June 5, 1924, but failed of passage in the Senate because of the legislative congestion in the closing days of the session:

Be it enacted, etc., That the Coast and Geodetic Survey is hereby authorized to make investigations and reports in seismology, including such investigations as have been heretofore performed by the Weather Bureau.

The transfer as above proposed was fully discussed by the two departments concerned, both of which were agreeable to its enactment.

In view of the necessity of effecting economies in the conduct of the work of the Weather Bureau, it was decided to discontinue, with the close of the fiscal year ending June 30, 1924, the publication of the table of Seismological Reports.—*Editor.*

SUBSTITUTION OF FRUIT TEMPERATURES FOR AIR TEMPERATURES IN REGULATING ORCHARD HEATING FOR ORANGES[1]

551.574 (794)

By FLOYD D. YOUNG, Meteorologist

[Weather Bureau Office, Los Angeles, Calif., August 27, 1924]

Orchard heating has been practiced to some extent in southern California citrus groves for more than 30 years. Throughout all of this period very little has been definitely known regarding the temperatures which will damage the fruit on the trees. The generally accepted critical temperatures are the results of the more or less unsystematic observations of the fruit growers themselves. Many of the thermometers used to record temperatures in the citrus groves have been inaccurate, and until the last few years practically all thermometers were poorly exposed.

Most orange growers who have orchard heating equipment very naturally wish to maintain a margin of safety, with the result that heaters often are lighted unnecessarily, and much fuel is wasted.

When investigations in connection with orchard heating were begun at Pomona, Calif., in the fall of 1917, the desirability of finding a method of eliminating some of the uncertainty regarding the proper time to light the heaters was recognized. Two methods of procedure were available: (1) To obtain accurate records of the air temperature in the orchards on cold nights, with special attention to duration of low temperatures, and to determine the amount of damage to the fruit which resulted; (2) to determine the practicability of regulating the firing by obtaining the temperature of the fruit itself, on the trees.

Data secured in connection with both methods will be discussed in this paper. It is desired to show that although a temperature of 27° F., indicated by an unsheltered thermometer, is generally considered to be the danger point for mature oranges, temperatures several degrees lower than this have occurred on several nights during a season without damage. Temperatures which have caused the loss of the entire crop in an orchard are given also, as a matter of information and record.

It is also desired to show that for efficiency in regulating the lighting of the orchard heaters, fruit temperatures are best; sheltered thermometer readings next; then readings of the unsheltered mercurial thermometer; and, least of all readings of unsheltered thermometers of other types.

LOW AIR TEMPERATURES AND RESULTING DAMAGE

Enough data were obtained during the winter of 1918–19 to indicate that the generally accepted critical temperature for oranges, 27° F., registered by thermometers exposed to the sky, was too high. During that season air temperatures in a naval orange grove were recorded as shown in Table 1. A standard minimum thermometer, exposed inside a fruit-region instrument shelter, 4½ feet above the ground, was used to record the lowest temperature each night, and a 29-hour thermograph recorded the duration of the low temperatures.

Only 3 per cent of the fruit harvested from this grove was so badly frozen as to be unmarketable. Twenty-nine per cent of the crop was frozen sufficiently to prevent its being included in the "Choice" or "Extra Choice" grades. So far as frost damage was concerned, the remaining 68 per cent of the crop was marketable as first grade fruit.

Thermometers exposed to the sky would have registered temperatures from one to three degrees lower than those in Table 1.

TABLE 1.—*Low temperatures and durations in navel orange groves near Pomona, Calif., winters of 1918–19, 1921–22, and 1922–23*

Date	Minimum temperature	Dew point	Type of night	Duration below 27° F.	
1918–19	°F.	°F.		H	m
Dec. 25	24.2	32	Moderately dry	4	25
30	24.4	[1] 46	Dry	4	40
31	24.1	28	do	9	55
Jan. 1	23.3	21	do	10	42
2	23.1	26	do	9	45
1922					
Jan. 20	19.8	12	do	12	33
21	22.0	22	do	13	0
22	24.6	22	do	8	10
23	25.2	29	Moderately dry	1	45
Feb. 3	25.1	28	do	2	49
1923					
Jan. 3	26.8	33	Damp	0	34
4	25.0	34	do	5	50
14	25.6	41	Very damp	4	50
28	26.6	37	do	0	47
Feb. 4	26.5	28	Damp	2	56
6	26.8	35	Very damp	0	40
7	26.2	38	do	2	5
8	27.0	41	do		
10	25.3	34	do	6	12

[1] Dewpoint fell to 21° F. before morning.

[1] Credit is due Mr. Edwin H. Jones for making the observations shown in Figures 5 and 7, and to Mr. C. W. Norman for making the observations shown in Figures 2 and 4 and a part of those shown in Figures 3 and 6. The writer desires to express his appreciation for the never-failing interest shown by Mr. Jones and Mr. Norman, despite the long hours of disagreeable night work.

FREEZE OF 1922

Warm days, and a lack of frosty mornings, together with the moist soil from heavy rains, kept the citrus trees in a growing condition throughout the winter of 1921–22, and the cold nights late in January probably caused a greater amount of damage than would have been caused in a normal season. As a general rule, the trees become semidormant during the colder winter months, due to the checking of new growth by early light, or moderately heavy, frosts.

Minimum temperatures and the duration of low temperatures in a navel orange grove during the 1921–22 frost season are given in Table 1. The trees in this grove were well cared for, and were in a vigorous condition at the time of the freeze. A heavy crop of fruit was on the trees.

From a close observation of the grove and the fruit on the trees, it is believed that the damage caused by the low temperature on the night of January 19–20 was total. A heavy drop of fruit began on the afternoon of the 20th, and some foliage damage was noticeable. Within two weeks practically the entire crop was on the ground.

1922–23 SEASON

There were very few nights with temperature near the danger point for oranges during the winter of 1922–23,

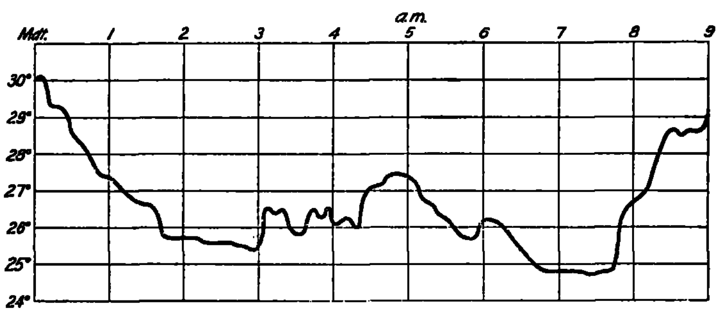

FIGURE 1.—Temperature record at station near Pomona, Calif., night of Jan. 1–2, 1924. Temperature fluctuations due to wind

and there was practically no damage by frost in the Pomona district. A temperature station was established at one of the coldest points in the district, in order to check on the amount of damage resulting from low temperatures. The lowest temperatures in this grove on every night with temperature near the danger point for oranges during the season, together with the duration of temperatures below 27° F., are given in Table 1. Orchard heaters were lighted in the Pomona district on five nights during the season. The firing was light and scattering except on the morning of February 10, when there was general firing up to the foothills.

Careful checks showed no evidence of damage to the interior of any of the fruit in the orchard at any time during the winter. A few "shiners" [1] were noted among the most exposed fruits on the trees, after the colder mornings, showing that the exposed rinds had been frozen, but the fruit itself had not been affected. At the time the fruit was picked, it was given an unusually careful examination at the packing house, but no frost damage was found.

Considering the fact that this particular grove was distinctly colder than the average in the district, it is interesting to note the number of times the heaters were lighted during the season. In the Pomona district alone 243,235 gallons of oil were delivered to the fruit growers during the winter. Probably only a small percentage of this fuel was burned, as most fruit growers carried over large quantities in storage at their ranches. However, when we consider that the amount of fuel consumed in the Pomona district was only a fraction of the total amount consumed in Los Angeles and San Bernardino Counties, it is apparent that the amount of fuel burned unnecessarily represented a substantial expense.

LOW TEMPERATURE WITHOUT DAMAGE

Minimum temperature records in another navel orange grove near Pomona, Calif., during the 1923–24 frost season are interesting because of the lack of damage to fruit. This grove had received excellent care and the trees were in a thrifty condition, with heavy foliage. For several years the grove had been heavily fertilized with bean straw, and the ground was entirely covered with dry bean straw during December, 1923, and January, 1924. The trees were about 15 years old.

Unfortunately there was no thermometer at this station, and the duration of the low temperatures on the different nights is not known. The lowest temperatures recorded at the station on each night during the season when the temperature fell below 27.5° F. are given in Table 2.

TABLE 2.—*Minimum temperatures in navel orange grove near Pomona, Calif., winter of 1923–24*

Date	Minimum temperature	Date	Minimum temperature
	°F.		°F.
Dec. 12, 1923	26.1	Jan. 21, 1924	27.2
Dec. 21, 1923	27.0	Jan. 23, 1924	27.1
Jan. 2, 1924	22.3	Jan. 24, 1924	27.0
Jan. 3, 1924	26.0		

The minimum temperature of 22.3° F., registered on the morning of January 2, was the lowest for the season in the entire district. Light puffs of wind during the night caused the temperature to fluctuate considerably, and it is probable that the temperature was at the lowest point only a short time. A record of the temperature on this night at the nearest station equipped with a thermograph, about a mile distant, is shown in Figure 1.

The fruit in this grove was inspected carefully at short intervals throughout the month of January, without finding any trace of frost injury. The thickness of the rind on the different fruits examined varied from one-eighth to one-fourth inch in extreme cases, with most of the rinds measuring three-sixteenths of an inch thick. The diameter of the fruits varied from 2⅝ to 2¼ inches.

Careful inspection was made of all the fruit from this grove at picking time by packing-house officials. The following is from the report made by the packing-house manager who handled the fruit:

> We have completed the last picking (April 18) and do not find enough frost damage to make mention of. There were very few drops, not over ten boxes on the whole grove. The grade averaged 70 per cent extra choice, 18 per cent choice, and 12 per cent culls. This may seem a little high on culls, but it is due mostly to wormholes and thrip, also quite a few splits.

The lack of damage in this orchard is an extreme case, and it is cited only to show what low temperatures oranges *may* endure without damage. It is probable that the lack of damage was due partly to the lag in the rate of fall in temperature in the fruit behind that of the outside air, and partly to "undercooling," which will be mentioned later. (See fig. 7.)

[1] Oranges on which the portion of the rind exposed to the sky has been frozen, leaving it a lighter yellow than the unfrozen rinds.

Fig. 2.—Fruit thermometer inserted in orange on tree. In actual practice the top of the thermometer would be pointing directly toward the camera

FRUIT THERMOMETERS

It is evident that the orchard heaters are often lighted unnecessarily, due to poor thermometers and poorer thermometer exposures. Even a well-exposed and accurate thermometer is intended to measure only the temperature of the air in the orchard, and the temperature of the fruit may often differ from the air temperature by several degrees. It appeared that a more natural and efficient method of determining when the heaters should be lighted would be to watch the temperature of the fruit instead of the temperature of the air.

In 1918 a special mercurial thermometer, 4 inches in length, made of heavy glass to avoid breakage, and carefully tested for accuracy, was furnished for this work. This type of thermometer was selected in preference to other types because of the fact that it could be used by the fruit growers if the experimental work showed this to be desirable. Several all-night series of fruit temperature readings were secured during the winter of 1918–19, but it was not until the winter of 1923–24 that time was available for making this work a major project.

The latest lot of these thermometers was purchased from the H. J. Green Co., Brooklyn, N. Y. They are graduated from about 20° F. to about 60° F., with an overflow-bulb for high temperatures. The wide temperature scale makes them easy to read. Following a high temperature, the mercury sometimes remains in the overflow bulb at the top of the tube, but it is easily forced back into the tube by whirling the thermometer. The thermometers have no backs, being simply thermometer tubes, somewhat similar to a clinical thermometer. Each instrument is furnished with a hard-rubber carrying case, in which it is well protected from breakage. The price of the fruit thermometer at the present time is $2.50 at the factory. A photograph of a fruit thermometer inserted in an orange is shown in Figure 2.

THERMOMETER EXPOSURES

The observations on which this paper is based were planned to bring out several points in connection with the improvement of orchard-heating practices which the fruit growers had been slow to accept. One of the more important of these is the matter of the exposure of thermometers in the orchards. It is well known that a thermometer exposed to the sky on a clear, calm night loses heat by radiation to the sky, and shows a temperature lower than the actual temperature of the air surrounding it. In other words, the exposed thermometer merely indicates its own temperature. This may be one, two, or even three degrees lower than the temperature of the air at the same elevation in the orchard, depending on the amount of moisture in the air and the type of thermometer used. Generally speaking, dark-colored substances radiate heat more rapidly than lighter-colored substances or those with a high polish. Thus two thermometers, one filled with mercury and the other filled with a dark-colored liquid, will show different temperatures when exposed side by side to a clear sky at night, even though they read the same when sheltered from the sky. With both instruments exposed to a clear sky, the mercurial thermometer will always show a higher temperature than the thermometer filled with dark-colored liquid, because of the higher rate of radiation from the dark-colored instrument.

Most fruit growers have contended that since the fruit on the trees is not sheltered from the sky, the sheltered thermometer will not indicate correctly the temperature of the fruit. As a matter of fact, from 85 to 90 per cent of the fruit on a healthy, vigorous orange tree is well screened from the sky by foliage. The records of the actual temperature of oranges on the trees show definitely that a sheltered thermometer indicates the temperature of even the outside fruit on the tree much more accurately than an exposed thermometer.

FRUIT TEMPERATURES

Records of the temperature inside oranges on the trees, together with temperature records obtained with different types of thermometers and varying exposures, are shown in Figures 3 to 8. Fruit temperatures were obtained by making a very small puncture in the rind of the orange and forcing the bulb of the small fruit thermometer through the rind, until the thermometer bulb was imbedded in the fruit pulp, just under the rind. The thermometer was always inserted at the most exposed spot on the orange, so that the temperatures obtained would be representative of the coldest section of the fruit. When oranges on the trees are only partially frozen, the injury is always found on the fruits on the outside of the tree and in the sections directly exposed to the sky. The careful forcing of the thermometer perpendicularly through the rind into the orange made a tight seal between the rind and the thermometer tube. Any liquid around the puncture was wiped off with a dry cloth.

The records in Figures 3 to 7 show that the mature naval oranges were, during the earlier portion of the night, nearly always warmer than the surrounding air, as indicated by the temperature inside the instrument shelter. Before freezing began, the most exposed oranges on the outside of the trees usually were from two to three degrees colder than those sheltered by foliage.

Temperatures indicated by thermometers exposed to the sky were from one to two degrees lower than those registered inside the instrument shelter. On the night of December 11–12, (fig. 3) the exposed thermometer indicated 27° F. at 11 p. m., while the temperature of the most exposed fruit did not reach that point until 3 a. m. If the lighting of the orchard heaters had been regulated by the unsheltered thermometer, the heaters would have been burned three or four hours unnecessarily.

UNDERCOOLING OF FRUIT

One of the most interesting points brought out in these investigations was the evidence that the juices of the oranges were sometimes cooled several degrees below their freezing point without the formation of ice. Physicists state that distilled water can be cooled many degrees below the freezing point without the formation of ice. Air-free water in sealed capillary tubes has been cooled to a temperature of 3° F. above zero without freezing. The instant the undercooled water begins to freeze, the latent heat liberated causes the temperature of the water to rise to the freezing point, 32° F. The temperature then remains at the freezing point until all the water has been frozen.

In the oranges which were used for these tests, the freezing point of the juice, which is indicated by the point at which the temperature of the fruit remained stationary after freezing had begun, varied from 26° to 28.5° F. The freezing point of the juices of different fruits on the same tree appeared to differ by as much as 1.5° F.

The greatest degree of undercooling occurred in an exposed orange on the night of January 1–2, when its temperature fell to 24.4° F. before it began to freeze.

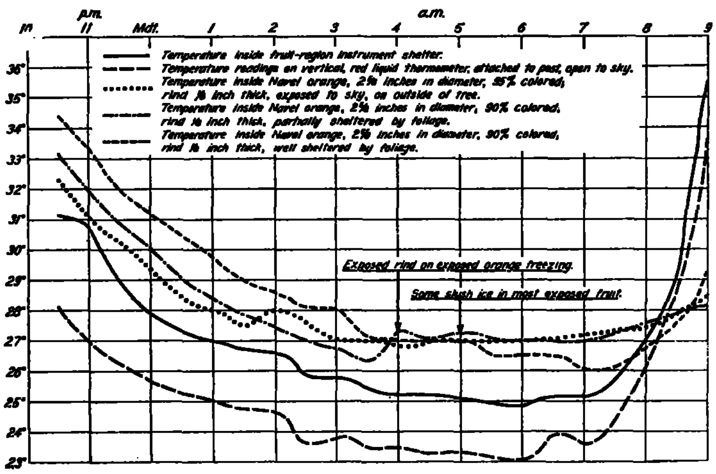

FIGURE 3.—Semihourly temperatures inside sheltered and exposed navel oranges on the trees in an orchard, Dec. 11–12, 1923, together with temperatures indicated by standard minimum thermometer inside instrument shelter, and by thermometer exposed to the sky. Exposed thermometer of a type in use generally throughout the California citrus districts, with black japaned metal case, and filled with a dark-red liquid. Exposed thermometer exposure same as in general use among fruit growers. All thermometers 4½ feet above ground. All had been checked for accuracy

Notes: Light, east wind, with heavy dust during the day on Dec. 11. Cloudless and practically calm all night. General light firing throughout district, with heavy smoke in the morning. Dewpoint 5 p. m. 31.5° F.; 6:30 p. m. 31°; 7:30 p. m. 29°. 1 a. m., heavy frost deposit forming on instrument shelter top. 4 a. m., portion of rind on exposed orange facing sky beginning to freeze (water mark showing). 5 a. m., some slush ice in exposed oranges. Noon, many "shiners" among exposed fruits. Some young and tender shoots killed

Note that the exposed thermometer had shown a temperature below 27° F. for five hours and had fallen to 23.5° F. before the most exposed oranges showed indications of freezing. The rise in temperature inside the partially sheltered orange between 3 a. m. and 3:30 a. m. was undoubtedly due to latent heat liberated in the freezing of the exposed portion of the rind. Oranges sheltered by foliage showed no indications of freezing at any time. They undoubtedly were undercooled. The long period during which the exposed and partially exposed oranges showed a temperature of 27° F. would indicate that their freezing point lies somewhere close to that temperature

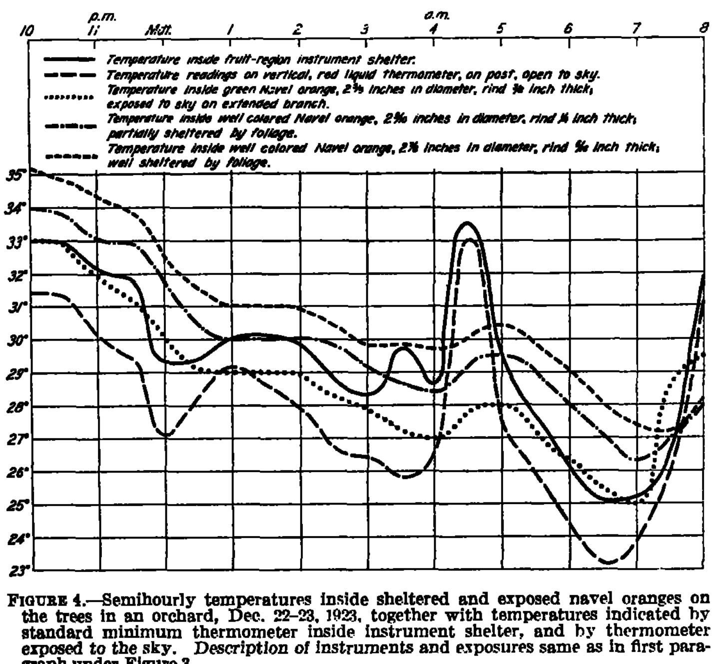

FIGURE 4.—Semihourly temperatures inside sheltered and exposed navel oranges on the trees in an orchard, Dec. 22–23, 1923, together with temperatures indicated by standard minimum thermometer inside instrument shelter, and by thermometer exposed to the sky. Description of instruments and exposures same as in first paragraph under Figure 3

Notes: Cloudless all day and all night, with heavy dust on horizon. Wind in streaks and at intervals during the night caused temperature to fluctuate. Dewpoint 5 p. m. 27° F.; 6:40 p. m. 31°; 7:45 p. m. 30°; 11 p. m. 25°; 2 a. m. 22°; 6 a. m. 23°. Exposed thermometers, leaves, and fruit remained perfectly dry all night. Very light frost deposit on instrument shelter top at 11 p. m.; no frost on ground. 1 a. m., no frost on ground; very little on shelter top. Ground in orchard very dry; evidently surface crust of frozen soil at this time. 4 a. m., thin film of ice forming on shelter top. 6 a. m., surface crust of ground frozen hard. 6:30 a. m., all oranges still soft, with no indication of freezing. 7 a. m., no indications of freezing of any fruit. 8 a. m., sun shining directly on exposed orange, but not on others. Although the exposed thermometer showed a temperature as low as 23.2° F. on this night, there was no indication of damage to any fruit

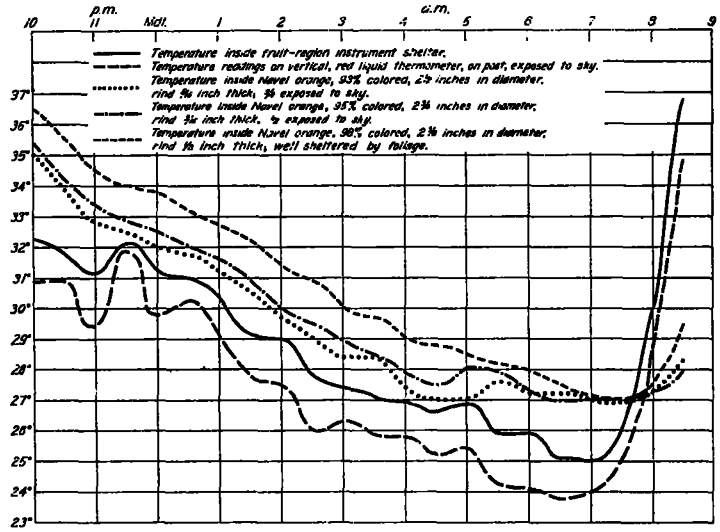

FIGURE 5.—Semihourly temperatures inside sheltered and exposed navel oranges on the trees in an orchard, Dec. 21–22, 1923, together with temperatures indicated by standard minimum thermometer inside instrument shelter, and by thermometer exposed to the sky. Description of instruments and exposures same as in first paragraph under Figure 3

Notes: A few scattering cirrus, cirro-stratus, and alto-stratus clouds during the day and up to 7:30 p. m. Sky cloudless during remainder of night. Light breezes all night caused temperature to fluctuate slightly. Dewpoint 5 p. m. 35° F.; 6:30 p. m. 41°; 7 p. m. 39°; 7:40 p. m. 35°. 10:30 p. m., heavy deposit of dew on exposed thermometers. 2:30 a. m., exposed thermometer completely covered with ice from frozen dew, with layer of frost outside. Necessary to scrape frost from scale to make temperature reading. 5 a. m., portions of rinds of exposed and partially exposed oranges facing the sky beginning to freeze (water mark showing). 7 a. m., all fruits remain perfectly soft. Large water marks on exposed and partially exposed fruits; none on sheltered fruits. Fruits and foliage covered with water or ice, and frost, from 10:30 p. m. until morning. Exposed thermometer showed temperature below 27° F. for five and one-half hours, with a minimum of 23.8°, with no damage to fruit

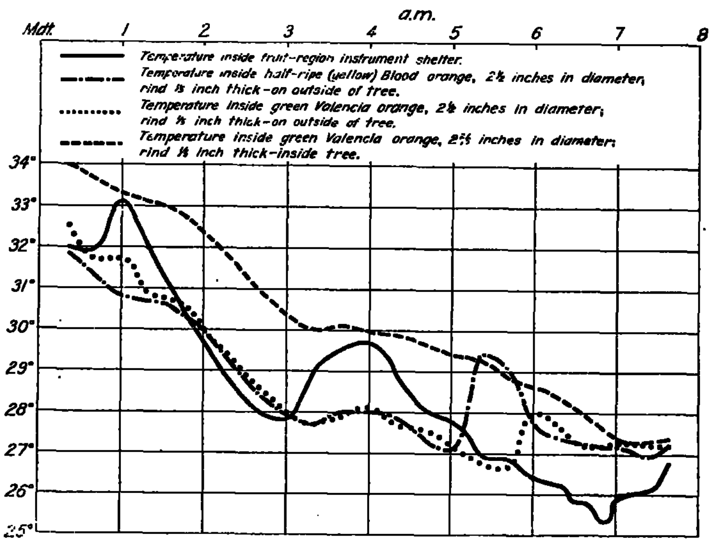

FIGURE 6.—Twenty-minute interval temperatures inside green Valencia orange sheltered by foliage, green Valencia orange exposed to sky, and half-ripe Blood orange exposed to sky, near Lindsay, Calif., on night of Dec. 3–4, 1923; also temperature registered inside thermometer shelter during the same period

Notes: Dewpoint 12:20 a. m. 28° F.; 2:40 a. m. 25°; 4:40 a. m. 25°; 6:20 a. m. 24°; 7 a. m. 25°. 6 a. m., exposed portions of rinds of fruits exposed to the sky beginning to freeze (water mark showing). 7 a. m., sunrise. 7:20 a. m., exposed rinds transparent (frozen) halfway through. No ice in oranges, nor any damage resulting, from this night's low temperatures. Fluctuations in air temperature due to wind. Sharp rises in temperature in exposed fruits between 5 and 6 a. m., probably due to liberation of latent heat in the freezing of the exposed portions of the rinds

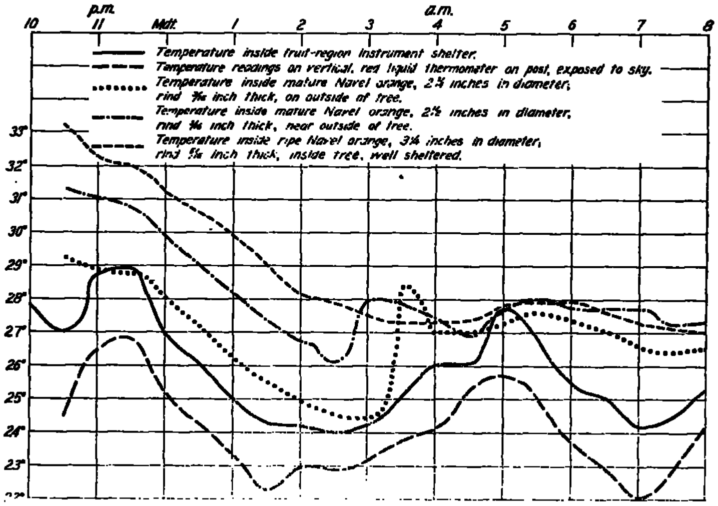

FIGURE 7.—Semihourly temperatures inside sheltered and exposed navel oranges on the trees in an orchard, Jan. 1-2, 1924, near Pomona, Calif., together with temperatures indicated by standard minimum thermometer inside instrument shelter, and by thermometer exposed to the sky. Description of instruments and exposures same as in first paragraph under Figure 3

Notes: Clear all day Jan. 1, with cool wind. Cloudless all night. Wind at intervals, causing fluctuating temperature. General firing over entire district, with unusually heavy smoke at sunrise. Clouds appeared before smoke cleared away in the morning, making conditions ideal for recovery of frozen fruit. Dewpoint 5 p. m. 24.5°; 6:30 p. m. 21°; 8:45 p. m. 24.5°; 10:30 p. m. 22°; 2 a. m. 25°; 4 a. m. 24°; 6 a. m. 23°; 7:30 a. m. 25°. 10 p. m., thin ice forming over puddles in road. 11:30 p. m., slight deposit of frost on instrument shelter top; no frost on leaves or fruit. 2:15 a. m., frost now beginning to form on exposed thermometer. None can yet be found on leaves. 2:30 a. m., light frost beginning to show on exposed leaves near the ground. 3 a. m., exposed thermometer now so heavily coasted with frost that reading is difficult. 4 a. m., rinds beginning to freeze (water marks showing) on all fruits. Surface layer of soil frozen solidly. No frost on foliage in upper portion of trees. 5 a. m., frozen areas on rinds of sheltered and partially exposed fruits growing larger. All test fruits remain soft. 6:30 a. m., heavy frost deposit on shelter top and on ground. Little frost on exposed fruit and leaves. Sheltered fruit and foliage dry. Thick ice on puddles. At 4:30 p. m. Jan. 2 many fruits showed plain evidence of injury from low temperatures of preceding night. On gophered trees, with little foliage, some exposed fruits showed brown spots on exposed rinds, a characteristic indication of frost damage. Many "shiners" on all trees. Note that the temperature of the exposed orange fell to 24.4° F. before freezing began, while the partially exposed orange began to freeze about 30 minutes earlier, at a temperature of 26.1° F. Up to 2:30 a. m. the temperature of the exposed orange was 3.5° lower than that of the sheltered orange, but after freezing began, all three fruits continued at nearly the same temperature. None of the fruits began to freeze until after the exposed thermometer had indicated a temperature of 22.3° F., and had shown a temperature below 27° F. for about five hours

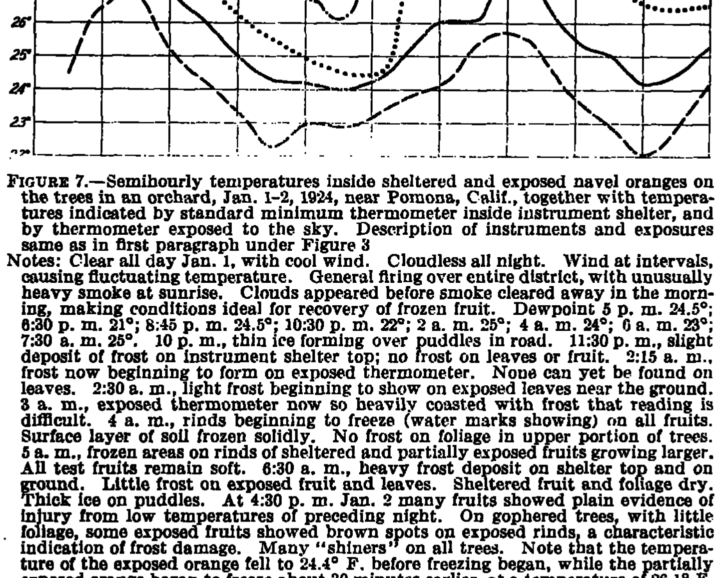

FIGURE 8.—Temperatures inside two mature navel oranges, exposed to the sky, and sheltered by foliage, respectively, on night of Dec. 9-10, 1923, near Lindsay, Calif; also readings of standard minimum thermometers, one inside instrument shelter and the other exposed to the sky in the orchard. Readings made at 20-minute intervals to 8 a. m., then 9 a. m., 9:30 a. m., and noon

Notes: Relative humidity 9:40 p. m., 78 per cent; 11 p. m., 85 per cent: midnight, 90 per cent; 1 a. m., 94 per cent; 3 a. m., 96 per cent; 8 a. m., 98 per cent. 10 p. m., portion of rind on exposed orange exposed to sky frozen. 11 p. m., slush ice in exposed oranges. 4 a. m., leaves curled. 4:40 a. m., exposed fruit firmly frozen. 5:20 a. m., slush ice inside sheltered oranges. 6 a. m., exposed oranges frozen hard. 6:20 a. m., sheltered oranges full of ice. 7:20 a. m., sunrise; smoky. The fruit in the orchard where this test was made was a total loss due to low temperatures on this one night. It is evident from the temperature records that both the sheltered and exposed oranges had already begun to freeze when the observations were begun. It is probable that the more or less constant temperatures which were maintained inside the fruits throughout the night were approximately the freezing points of the juices, or slightly below these points. Although the air temperature was below the freezing point of the fruit juices for 11 hours or longer on this night, reaching a minimum temperature of 19° F., the temperature of the sheltered orange still remained practically stationary at the end of this period, due to the liberation of latent heat.

(See fig. 7.) On the night of December 11-12, 1923, all of the fruits in which temperature readings were obtained began to freeze as soon as the freezing point of the juice was reached, with little or no undercooling. (See fig. 3.)

While the limited number of records at hand makes it impossible to draw any definite conclusions, it appears that ripe navel oranges are likely to be cooled below the freezing point of the fruit on most still, cold nights of winter, but it is not possible to determine in advance what the degree of undercooling will be before the fruit begins to freeze. On the night of January 1-2, 1924, although the temperature of the exposed fruit was running more than 1.5° F. lower than the temperature of the partially sheltered orange on the same tree, the partially sheltered orange began to freeze earlier and at a higher temperature than the exposed fruit. This is shown graphically in Figure 7. As illustrated in Figure 3, there may be no undercooling at all, as the fruit may begin to freeze as soon as its temperature has fallen below the freezing point of the juice.

After the fruit has begun to freeze, its temperature will remain at or near the freezing point of the juice as long as the freezing continues. However, there were some slight fluctuations of temperature inside the fruit after freezing had begun. As a general rule, when the fruit had been undercooled, the temperature rose suddenly several degrees when freezing began, and then fell slightly. This is illustrated in Figure 7. The temperature of the exposed orange fell to 24.4° F. before freezing began, rose rapidly to 28.4° F. on freezing, and then fell back to 27° F. On the same night the temperature of the partially exposed orange fell 1.1° F. after the crest of the rise that took place when freezing began.

There are two possible explanations for this:

1. If the orange is on the outside of the tree, the portion of the rind exposed to the sky always freezes before any other part. When the rind begins to freeze it takes on a peculiar transparent or water-soaked appearance which is quite noticeable. This is known among citrus growers as the "water mark." Very often the freezing does not extend through the rind, but rinds which have been frozen can always be pointed out for at least several days after a freeze. The portion of the rind that has been frozen becomes a lighter color than the unfrozen portion. Such fruits are called locally "shiners." In every case where oranges were undercooled in these experiments, the sharp rise in temperature to the freezing point, due to the release of latent heat, was coincident with the appearance of the "water mark" on the rind. Possibly the moisture in the rind has a slightly higher freezing point than the juice of the fruit, so that the initial rise in temperature at the beginning of the freezing is due to latent heat from the freezing of the rind.[3] If the amount of undercooling has been considerable, the temperature quickly rises to the freezing point of the moisture in the rind when freezing begins, but as the rind is soon frozen through, the temperature falls back to the freezing point of the fruit juice. This is merely a tentative explanation, and has not been verified.

2. After the exposed portion of the rind has been frozen through, the freezing continues in the portion of the fruit directly underneath, in which the bulb of the fruit thermometer was embedded. The portion of the orange facing away from the sky, toward the interior of the tree, is warmer than the exposed portion, because it is sheltered

[3] Since freezing must progress through the rind into the pulp, it does not seem necessary that the moisture in the rind should have a higher freezing point than the juice of the fruit. Temperature during the undercooling would reach a given value in the rind first, and later in the pulp. Hence undercooling would "set off" freezing and the liberation of latent heat first in the rind, with the possibility, as Mr. Young points out, of thus causing a coincident rise of temperature to the freezing point within the fruit.—*B. M. V.*

from the sky, and there must be a conduction of heat from the warmer portions of the orange to the colder exposed portion. (The most exposed segment of the fruit often shows severe injury following a freeze, while the remainder shows no injury.) Assuming that the most exposed portion of the fruit, in which the thermometer is embedded, has been frozen, so that the latent heat in that particular section of the fruit has all been liberated, the only means whereby the temperature in this frozen section is maintained above the temperature of the surrounding air is through the conduction of heat from the unfrozen, or freezing, portions of the fruit. In some cases the rate of conduction of heat may be lowered to the point where the fruit thermometer shows a temperature somewhat below the freezing point of the juice.

The presence of different substances in solution in the orange juice, some of them of a complex organic character, must also have some influence on the freezing point of the orange at different stages in the freezing process.

The large amount of latent heat liberated in the freezing of an entire orange is well illustrated in the records obtained on the night of December 9–10, 1923. (Fig. 8.) Both oranges used in tests on this night had already begun to freeze when the observations were begun, shortly after 9:30 p. m., and probably had been freezing for an hour or more. The total length of time the oranges were freezing on this night was probably about 12 hours, yet the amount of latent heat liberated was sufficient to prevent the temperature of the exposed fruit from falling below 25.9°. The temperature of the sheltered fruit was maintained at about the freezing point of the juice throughout most of the night. The observer states in his notes that the exposed orange was "frozen hard" at 6 a. m., but the freezing evidently was still continuing in some portion of the fruit at that time, since the fruit thermometer showed only a very slight fall in temperature between 6 a. m. and 8 a. m., when the air temperature began to rise.

CONCLUSIONS

The work on the freezing of oranges on the trees under natural conditions, described in this paper, was of a preliminary nature, and the amount of data secured is insufficient to reach any final conclusions. Nevertheless Figures 3 to 8 present an interesting picture of the relationship between the temperatures in the orchard and those inside the fruit, on the particular frosty nights on which the records were made. They should be of value to all orange growers, and particularly to those who protect their crops from frost damage.

The fruit temperature records secured during the winter of 1923–24 indicate that undercooling of the fruit is likely to take place on cold nights, but the degree of undercooling before freezing begins varies greatly, even in different fruits on the same tree, so that when artificial means of heating the orchard are available, it is not safe to allow the temperature to fall below the freezing point of the juice. It is probable that undercooling of fruit, without any freezing, during a cold night, has been responsible for many cases of unusually low temperatures without damage that have been reported in the past.

In determining when it is necessary to light the orchard heaters through the aid of fruit temperatures, it will be necessary for the fruit grower to light the heaters before the temperature inside the fruit has reached the freezing point of the juice. Since this point appears to differ in different fruits, even on the same tree, it will be necessary to take the highest freezing point that has been determined experimentally, rather than the lowest, as a guide. It is believed that thousands of dollars' worth of orchard-heater fuel can be saved during the average frost season by substituting fruit temperatures for temperature readings made with unsheltered thermometers in the orchards.

If the fruit grower finds it impracticable to use the fruit thermometer because of difficulty in reading the small scale, or on account of inexperienced help, or other reason, a thermometer in a shelter should be used. If a thermometer thus sheltered is not used, a mercurial thermometer is preferable to any other type, because the mercurial thermometer is less influenced by radiation of heat to the sky. It should be emphasized that only the use of the fruit thermometer will give the desired fruit temperature.

There has been great difference of opinion in southern California as to the influence of moisture, or lack of moisture, in the air and surface soil, on the amount of damage resulting from a given low temperature. It is hoped to be able to decide this question definitely when more fruit temperature data have been secured.

It seems very probable that the greater amount of damaged fruit found on diseased or neglected orange trees following a heavy frost is due largely to lack of foliage. Figures 3 to 7 indicate that on most frosty nights the exposed fruits cool more rapidly and begin to freeze earlier than those sheltered from the sky by foliage. Experience has shown that practically all the fruit on the outside of the trees is often lost through frost damage, while the fruit inside the tree shows little or no injury. It follows that the larger the percentage of fruit unsheltered by foliage, the greater will be the percentage of loss by freezing, with the same degree and duration of low temperature.

Undoubtedly the amount of damage to a mature orange resulting from a given low temperature depends to some extent on the thickness of the rind. A thick, pithy rind affords considerable protection to the interior of the fruit. There is considerable variation in the thickness of the rinds of oranges of the same variety grown in different districts in southern California, and some variation in this particular in different trees in the same district.

The fruit temperature observations showed that small oranges cooled more rapidly than large oranges with similar exposures, although the difference in the rate of cooling was less than might have been expected.

Observations of the freezing of citrus fruits on the trees under natural conditions entail a great deal of unpleasant night work, but it would be very difficult, if not impossible to duplicate the natural conditions to which trees and fruit are subjected on frosty nights, by artificial means. If fruits on the inside and outside of the tree were subjected to the same cooling influences on a cold night—in other words, if the cooling of the outside fruit by radiation of heat to the sky were absent—artificial methods of freezing trees and fruit might represent very closely the natural conditions. Since no method of duplicating artificially the conditions which occur in the orchards on frosty nights is available, it seems quite necessary that the work outlined in this paper be continued. Experimental freezing of fruit on the trees by artificial means will yield valuable data on the freezing point of fruits, amount of undercooling, and other important points.[3] Some work of this kind has already been done.

[3] Hawkins, Lon A. "Investigations on the Freezing of Citrus Fruit on Trees"; California Citrograph; March, 1924; IX; 163.

There appears to be little doubt that the use of the mercurial fruit thermometers by the fruit growers is entirely practicable. When this has been thoroughly demonstrated, other types of thermometers may be substituted in the experimental work, in order to make the work less tedious.

It is not to be expected that all orange growers will immediately adopt the fruit thermometer for regulating the time of lighting their orchard heaters; indeed such a sudden, radical change is not to be recommended. In all cases the fruit grower should continue to use accurate, sheltered thermometers to obtain the temperature of the air in the orchard, and when the use of the fruit thermometer is first begun it should be only to supplement the information obtained from the sheltered thermometer. The average fruit grower is likely to meet with minor difficulties in obtaining fruit temperatures at first, and he should not depend on such readings until he is sure he thoroughly understands how to use them.

Probably some growers will prefer to continue to use the old methods of obtaining the temperature, if they feel that the men charged with reading the thermometers are not thoroughly trustworthy. On the other hand, the use of the fruit thermometers will not be difficult in any way after the orchard heating crew has become familiar with them, and it is believed that eventually most orange growers will consider them almost indispensable in handling orchard heating.

During the winter of 1923–24 a large number of records was secured showing the temperature inside lemons on the trees during frosty nights, in the same manner as that in which the orange temperatures were secured. The results of these observations will be published later.

OSCILLATIONS OF THE ATMOSPHERIC CIRCULATION OVER THE NORTH ATLANTIC OCEAN IN THE 25-YEAR PERIOD, 1881-1905 [4]

551.513 (261.1)

By A. Defant

[Innsbruck]

[Translated from the German by W. W. Reed; abstracted and condensed by B. M. Varney]

In the paper: "Die Verteilung des Luftdruckes uber dem Nordatlantischen Ozean, etc.,"[5] were given for each month of the year new charts of mean air-pressure distribution for the whole region covered by the daily synoptic weather charts issued by the Deutsche Seewarte and the Danish meteorological service. Each chart is the mean of the 25 charts of a given month for the period 1881–1905. By the basis of them we may obtain the air-pressure anomalies for that period in the region under consideration. This extensive material furnishes an excellent basis for investigations of nonperiodic changes in the distribution of air pressure as well as of oscillations of the atmospheric circulation over the North Atlantic Ocean and adjacent lands. In the following pages will be set forth some of the most important results of investigations carried out on the basis of these charts. They constitute only a partial elaboration of the material from certain points of view, in order that the investigation should not be too voluminous.

1. *Air-pressure anomalies over the North Atlantic Ocean.*—If we compare anomalies with mean pressures at the intersections of parallels (5° apart) with meridians (10° apart), it appears that in the majority of cases the distribution of the anomaly belongs to a definite system which is a unit in itself. Hence it appeared desirable to confine the investigations to anomalies of pressure over the ocean, leaving out of consideration the extensive adjoining region of the European Continent. The North Atlantic was considered to include the region between 60° and 10° west longitude and from 75° to 10° north latitude. In all there are included 84 intersection points, so that the distribution of anomalies was given by 84 values.

The fact that on the whole the anomaly in the direction of each parallel had the same sign and the same magnitude makes it appear permissible to form mean values in the direction of the parallels for the entire region. Thus we obtain for each month a mean distribution of air-pressure anomaly in a north-south direction between 75° and 10° north latitude. Each value is the mean of the six values between 60° and 10° west longitude. These monthly values give at once a satisfactory view of the kind and magnitude of the departure of air pressure in the month considered, while in their succession they afford a history of air-pressure shiftings over the Atlantic Ocean. This is the first time that a summarized representation of air-pressure departures from normal for a period of 300 months has been compiled for such an extended region of the earth.

In this meridional distribution of air-pressure anomalies over the Atlantic one may very clearly discern the appearance and recurrence of certain characteristic types of anomaly. It is possible, without making too liberal an interpretation of the material, to arrange the 300 successive cases under four types, to which can be assigned indices of intensity of the departures occurring in them.

In type A there lies over the North Atlantic a region of positive pressure anomaly. It extends from the far north to about latitude 50° north, and on an average its center lies near 65° north in the vicinity of Iceland. South of this extends a region of negative anomaly, centered near latitude 40° north, which, gradually diminishing, extends to the thermal equator (10° north latitude). North and south have therefore opposite anomalies, atmospheric pressure in the north being relatively too high and in the south relatively too low. Of the 300 cases, 113, or nearly 38 per cent, fall under this type.

Type B shows the opposite distribution; the negative anomaly reaches from the far north to latitude 50°, with its center at 65°. The positive anomaly extends to latitude 10° north, with its center near 40°. Type B is thus exactly opposed to type A. One hundred and thirty-seven months show the type B distribution, or 46 per cent of all cases. Under A and B occur in the aggregate 83 per cent of all cases. The remaining 17 per cent excepting four cases in which it was difficult to make determination, belong to two other types, which again are opposed to each other.

Type C is related to type A; the positive anomaly usually extends from the far north to 35° north latitude and is centered between 55° and 50° north. The negative anomaly includes the whole southern portion. Twenty-five cases fall under type C. The exactly opposed type D, which is related to type B, appears in 21 cases.

If we combine types A and C, which show a pressure relatively too high in the north and too low in the south, they together include 138 months, or 46 per cent. Under

[4] Geografiska Annaler, 1924, H. 1, pp. 13–41.
[5] Denkschr. der Wiener Akad., Band 93, 1916.